Development of Biodegradable Hydraulic Fluids for Military Applications

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Background

Hydraulic systems are essential component of military equipment ranging from aircraft flight control systems to construction equipment. A common factor in most hydraulic systems is the potential for leakage and the possibility of spillage of hydraulic fluid during storage and use. The generation of the hazardous wastes by petroleum based or synthetic fluids results in both short and long term liability in terms of costs, environmental damage, and mission performance. Currently, the Resource Conservation and Recovery Act (RCRA) and DoD Hazardous Minimization (HAZMIN) Policy mandate that all military installations must reduce the quantity or volume and toxicity of hazardous waste generated by petroleum based products wherever economically practicable and environmentally necessary. To achieve the environmental goals, a number of recycling, re-refining, incineration, and field bioremetiation technologies were recently used in the field, but with limited success. For this reason, Fuels and Lubricants Technology Team of U.S. Army Tank-Automotive Research, Development and Engineering Center is currently developing Biodegradable Hydraulic Fluids (BHFs) to replace military industrial and mobility hydraulic fluids which are less compatible with environment.

In response to the demand of military BHFs, a market study was conducted in 1994 to determine whether renewable hydraulic fluids would be suitable in military applications. In this study, total twenty-six (26) renewable hydraulic fluids were evaluated against the requirements of MIL-H-46001[1] as most samples were designed as industrial hydraulic fluids. The result showed that most renewable hydraulic fluids tested were very close to meeting requirements of MIL-H-46001 specification and were promising as candidate biodegradable military hydraulic fluids. These results were published in TARDEC Technical Report[2] entitled " Evaluation of Environmentally Acceptable Hydraulic Fluids". However, these renewable products must be reformulated for use in military applications as they were originally designed for the limited commercial applications. Further development of this effort was devoted to develop the target requirements for BHF and to conduct the field validation for these renewable products. This paper review market study, and describes the market study, target requirement of BHFs, laboratory test results, finding, and details the field demonstration that is being currently conducted at Fort Bliss, TX.

Market Survey

A market survey for BHFs has been conducted to determine whether renewable hydraulic fluids would be suitable in military applications. The approach used in this study was to review laboratory data and current technology used in BHFs, and to determine availability of BHFs including manufacturers. Currently, there are two types of BHFs available. These types of fluids are either vegetable based or synthetic ester based. Each of these fluids has significant different characteristics from conventional mineral oil. As a follow-up action, twenty-six (26) renewable hydraulic fluids were evaluated against the requirements of military industrial hydraulic specification, MIL-H-46001[2].

Vegetable oils have excellent lubrication qualities and are nontoxic and biodegradable. They are made from renewable resources such as rapeseed, sunflower, corn, canola and soybean, and are much less expensive than synthetic fluids. Their chemical structures are triglycerides in which a variety of saturated, monounsaturated or polyunsaturated fatty acids are esterified to a glycerol backbone. The physical properties of a vegetable oil depend on the nature of its fatty acid composition. This oil tends to oxidize at temperature above 90 °C and short life compared with conventional petroleum-based fluids, Also, it has a limited low temperature capability (-15 °C). This significantly affects the outdoor mobility applications where hydraulic systems may sit for extended period at sub-zero temperatures. However, only one type of viscosity grade (i.e., ISO 32) is available due to its limited manufacturing process.

Synthetic esters, mainly based on trimethylopropane, polyol ester and pentaerythritol, are regarded as the best among the biodegradable base fluids. The biodegradability of these oils is comparable to vegetable oils and their lubrication properties are very similar to mineral oils. The advantages of these oils are excellent fluidity, and low temperature and aging stability. Because of these, they provide wide operational temperatures (-54 to 150 °C) and have long shelf and service lives. One the other hand, the cost of synthetic esters is much higher than those of mineral oils. Their differences are summarized in Table 1.

Table 1. Comparison of Base Fluids

	Mineral Oils	Vegetable Oils	Synthetic Esters
Biodegradability ASTM D 5864, %	10-40	40-80	30-80
Viscosity Index	90-100	100-250	120-220
Pour Points, °C	-54 to –15	-20 to 10	-60 to –20
Compatibility with Mineral Oils	-	Good	Good
Oxidation Stability	Good	Poor to Good	Poor to Good
Service Life	2 yrs	6 month to 1 yr	3 yrs
Relative cost	1	2 to 3	4-6

It was found that BHFs also require additive to enhance performance. Antioxidations, corrosion inhibitors and pour point stabilizers can improve the lubrication properties of some vegetable oils such as rapeseed oil and synthetic esters. However, the use of conventional additives in BHFs may pose potential problems on the fluid's biodegradability and ecotoxicological properties due to the toxicity of chemicals. Thus, domestic additive manufacturers are also investing in developing the BHF additives, which are compatible with BHFs. Some environmentally acceptable additives such as sulfur-carriers have been developed and are currently available in domestic market.

Development of Preliminary Target Requirements for BHFs

The new target requirements for military BHFs were developed based on the specific military needs and what is believed to be achievable with the current BHF formulation technology. Most target requirements were consolidated with the current military hydraulic fluid specifications (MIL-H-46001, MIL-H-6083, MIL-H-46170)[3,4]. These target requirements were designed for Types I and II, which tend to cover all types of renewable hydraulic fluids such as vegetable or synthetic biodegradable fluids. Especially, Type I was designed for vegetable-based hydraulic fluids, while the synthetic BHFs are listed as Type II fluids. These fluids were also divided into five categories based on the ISO viscosity grades. Table 2 lists the preliminary target requirements for BHFs.

To develop a BHF specification, the preliminary target requirements tend to cover a wide operational temperature ranges (-54 to 150 °C), a high biodegradability, a wide viscosity ranges, excellent antiwear and load carrying capacity, good elastomer compatibility, good oxidation stability, good fire resistance, and excellent rust and corrosion protection. Most test methods specified in these requirements were the ASTM standard test methods that are normally used for evaluating the current military hydraulic fluids. Specially, an ASTM biodegradable test method was adopted to evaluate the biodegradability of BHFs. This test method was designed to determine the degree of aerobic aquatic biodegradation of fully formulated lubricants or additives on exposure to an inoculum under laboratory conditions. A toxicity test is also required to assess the environmental properties.

To verify the preliminary target requirements, eleven (11) interim BHFs were reformulated by several lubricant companies and tested according to the testing protocol. The test results obtained to date are presented in Table 3. All interim products met most requirements and provided very high flash and fire points that are compare with those of military fire resistant type hydraulic fluids. The rapeseed–based fluid provided the highest biodegradability among all the fluids. Some of fluids having a high viscosity had a difficulty meeting the target requirement of biodegradability due to their heavy molecular weight and the types of materials. This target requirement may be readjusted to accept new BHFs.

Field Demonstration

As a result of the successful completion of earlier phases of this program, a field demonstration was initiated at Fort Bliss, TX using five (5) BHFs (i.e., rapeseed oil, canola oil, soybean oil polyol ester, diester) and ten (10) construction equipment (i.e., scoop loaders, dump trucks, road graders, etc.). The test samples and equipment are listed in Table 4. For the test, the existing hydraulic fluids were completely removed from equipment prior to the introduction of BHFs. To verify the test results, each BHF was set up in two different types of equipment. The evaluation criteria used in this demonstration are their field performances (i.e., oxidation, viscosity change, wear problem, corrosion protection, seal problem, etc.) and environmental performances (i.e., biodegradability, toxicity). The duration of these tests was designed as one year. The field test is currently conducted by the TARDEC Fuels and Lubricants Research Facility of Southwest Research Institute (SwRI). A quarterly progress review was performed at the each site, and field samples were collected for the laboratory analysis.

Although the field demonstration is not completed, the interim results showed that all candidate BHF samples did not give any abnormal behavior during six month and provided excellent service. However, the laboratory tests are being conducted and the results will be reported at the end of the field demonstration.

Conclusions

On the basis of the work completed to date, Most BHFs were very close to meeting the proposed target requirements and are promising as the candidate military BHFs. As a follow-up action, a field demonstration is being conducted at Fort Bliss. Based on the interim results, BHFs do not create any abnormal behavior when compared to the conventional hydraulic fluids. Therefore, BHFs can be used in selected military hydraulic systems. The results of this study are summarized in the following finding:

- Numerous BHFs are currently available in domestic market and new products are being developed to meet the commercial and military requirements.
- BHFs are biodegradable and less toxic products, and were formulated using vegetable oils (i.e., rapeseed, sunflower, corn, soybean, canola) and synthetic esters.
- Vegetable-based BHFs have limited operational temperature ranges (-10 °C to 90 °C) due to poor thermal and low temperature stability. On the other hand, synthetic ester based fluids showed wide operational capability (-54 °C to 150 °C) which can be used as military mobile hydraulic fluids
- Proposed target requirements were developed based on the market study and military specific requirements.
- Eleven (11) interim BHFs were formulated by the lubricant industries and were evaluated against the target requirements. Most of These products were very close to meeting the target requirements.
- A field demonstration was initiated using five (5) BHFs and ten (10) construction equipment (i.e., Loader Backhole, Dump truck, Grader road, etc.) at Fort Bliss, TX. Although the field test is not completed, all field samples gave a good performance and did not show any abnormal behavior in the selected construction equipment.
- As a plan, this field demonstration will be extended to the military tactical vehicle applications (i.e., tanks, artillery, etc.).

References

1. Military Specification MIL-H-46001, Hydraulic Fluids, Petroleum Based, For Machine Tools, 7 December 1989.
2. In-Sik Rhee "Evaluation of Environmentally Acceptable Hydraulic Fluids", NLGI Spokesman, 1996.
3, Military Specification MIL-H-6083, Hydraulic Fluid, Petroleum Base, For Preservation and Operation, 8 February 1990.

4. Military Specification MIL-H-46170, Hydraulic Fluid, Rust Inhibited, Fire Resistant, 17, November 1993.

Table 2. Target Requirements for Military Biodegradable Hydraulic Fluids

Test	Method	Type I	Type II				
			A	B	C	D	E
ISO Grade	ASTM D2422	NR	15	32	46	68	100
Viscosity, 40 °C min, cSt	ASTM D445	34.2-41.8	13.5-16.5	28.8-35.2	41.4-50.6	61.2-74.8	90.0-110
Viscosity Index, min	ASTM D2270	184	140	140	140	140	140
Viscosity, -15°C, max, cSt	ASTM D445	2300	200	1000	1300	1500	NR
Pour point, °C, max	ASTM D97	-25	-54	-40	-26	-26	-12
Flash point, °C, min	ASTM D92	250	180	240	240	250	250
Fire point, °C, min	ASTM D92	320	190	260	260	260	260
Acid or base number, mg KOH/g, max	ASTM D664	1	1	1	1	1	1
Water content, %, max	ASTM D1744	0.05	0.05	0.05	0.05	0.05	0.05
Rust prevention	ASTM D665B	pass	pass	pass	pass	pass	pass
Copper corrosion, max	ASTM D130	1b	1b	1b	1b	1b	1b
Galvanic corrosion	FTM 5322	pass	pass	pass	pass	pass	pass
Low temperature stability, -15 °C, 72 hrs	FTM 3458	pass	pass (-54 °C)	pass	pass	pass	pass
Oxidation stability (PDSC), minutes, min	ASTM D6186	20 (155 °C)	20 (180 °C)	20 (180 °C)	20 (180 °C)	20 (180 °C)	20 (180 °C)
Thermal stability, mg/100 ml, max	ASTM D2070	25	25	25	25	25	25
Swelling of synthetic rubber, NBR-L, %, max	FTM 3603	35	35	35	35	35	35
Evaporation loss, %, 100 °C, 1 hr, max	ASTM E1131	2	2	2	2	2	2
Four ball wear, mm, max	ASTM D4172	0.65	0.65	0.65	0.65	0.65	0.65
Biodegradability, %, min	ASTM D5864	60	60	60	60	40	40
Toxicity, min	ASTM D6081						
Foaming	ASTM D892	65/10	65/10	65/10	65/10	65/10	65/10
Workmanship	Army method	pass	pass	pass	pass	pass	pass
Particle size[1]	particle counter	pass	pass	pass	pass	pass	pass
Storage stability[2], 100 °C, 1 month	Army method	pass,	pass	pass	pass	pass	pass

1. Particle size ranges — Allowable number (max)

Particle size ranges	Allowable number (max)
5-25	10,000
26-50	250
51-100	50
over 100	10

2. Storage stability

Viscosity change	10 %
PDSC, induction time change	10 %
Acid number change, mg, max	2 mg

Table 3. Biodegradable Hydraulic Fluids – Physical property Data

Product Code	Type	Base stock	Viscosity 40 °C	Viscosity -15 °C	Pour point °C	Flash point °C	Acid No.	Four ball wear, mm	Biodegradability, %
A	I	Canola	35.8	575.5	-30	284	0.79	0.4	80
B	I	Rapeseed + Mineral oil	40.2	ND*	-12	318	0.54	0.58	73
C	I	Soybean	48.3	953.9	-26	266	2.17	0.3	60
D	I	Canola + Polyol ester	42.3	695	-37	254	2.10	0.4	71
E	I	Rapeseed	39.2	649.8	-30	316	1.32	0.55	67
F	I	Canola	41.3	ND	-39	216	2.35	0.3	62
G	IIA	Dibasic ester + vegetable oil	13.9	ND	-60	250	0.83	0.3	48
H	IIB	Dibasic ester + vegetable oil	33.6	ND	-60	242	0.82	0.33	ND
I	IIC	Dibasic ester + vegetable oil	52.7	ND	-60	250	0.88	0.33	ND
J	IID	Dibasic ester + vegetable oil	81.6	ND	-60	242	0.96	0.35	ND
K	IIE	Dibasic ester + vegetable oil	116.6	ND	-60	252	0.93	0.34	41

* Not determined

Table 4. Field Demonstration of Biodegradable Hydraulic Fluids at Fort Bliss, TX

Code	Construction Equipment	Candidate BHF	Laboratory product code
FBHF1	Loader Backhoe (John Deere)	Rapeseed oil	E
FBHF2	Dump Truck (International)	Canola oil	A
FBHF3	Dump Truck (GMC)	Canola oil	F
FBHF4	Dump Truck (International)	Soybean oil	C
FBHF5	Grader Road 130 G	Soybean oil	E
FBHF6	Loader Scoop MW24C	Canola oil	A
FBHF7	Grader Road	Rapeseed oil	C
FBHF8	Grader Road 130 G	Synthetic oil	H
FBHF9	Loader Scoop	Synthetic oil	H
FBHF10	Wrecker Truck M816	Canola oil	F

Environmental temperature ranges: 10 °F- 100 °F